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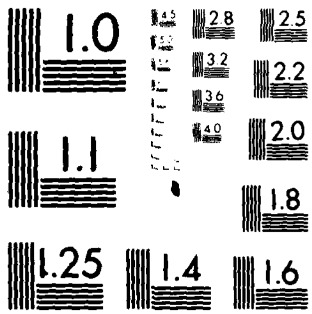

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THE STUDY OF FACTORS AFFECTING THE PRECISE ESTIMATION OF THE EARTH'S GRAVITY FIELD

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Final Report
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This report summarizes the work done in the three year period of the contract. Brief remarks are made concerning research in the following areas: new analysis techniques for data given on a spherical grid; analysis of satellite-to-satellite tracking data; global gravity field modelling; and the vertical datum problem. A complete list of papers and reports produced under contract sponsorship are listed.

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Foreword

This report was prepared by Richard H. Rapp, Professor, Department of Geodetic Science and Surveying, at The Ohio State University under Air Force Contract No. F19628-79-C-0027. This report is the final report of the contract that started December 1, 1978 and ended October 31, 1981. This project has been administered by the Air Force Geophysics Laboratory, Air Force Systems Command, Hanscom AFB, Massachusetts. From the start of the contract to August, 1981 the Contract Manager was Bela Szabo. From August 1981, the Contract Manager has been George Hadgigeorge. The project was administered at The Ohio State University through OSU Research Foundation project number 711664.

1. Introduction

This final report is being written to briefly describe the research conducted under contract No. F19628-79-C-0027 from December 1, 1978 to October 31, 1981. The research has been carried ou the theme of the contract title: The Study of Factors Affecting the Precise Estimation of the Earth's Gravity Field. The research has been conducted by three graduate research associates, three post doctoral researcher, and the principal investigator. The research results have been reported in detail, in 12 Scientific Reports of the contract and 8 papers presented at various meetings. In addition, quarterly reports have been made to the Contract Manager from the start of the project.

It does not seem appropriate to detail the research that has been described earlier. However, it is appropriate to describe areas of study, the reports associated with each one, and the most significant contributions.

A complete list of reports, by scientific report number is given in section 4. A list of the papers presented at meetings is given in section 5, and a list of persons employed under the contract is given in section 3.

2. Areas of Study

The research can be described in the following four categories: new analysis techniques for data given on a spherical grid; analysis of satellite-to-satellite tracking data; global gravity field modelling; and the vertical datum problem.

New Analysis Techniques For Data Given on a Spherical Grid

Many geodetic problems require the analysis of data given on a spherical surface representing the earth. As an example, we have the calculation of geoid undulations and potential coefficients from mean gravity anomalies. As the number of surface elements increases, and the number of quantities of interest increase the computational effort can significantly increase. This is especially true if an optimal estimation of the parameters, considering data noise and other factors, is to be done.

Colombo (Sci. Rpt. No. 1, 1979) examined the application of least squares collocation to data given on a uniform spherical grid. In this report a theoretical analysis was carried out with both point and area mean data. Of special theoretical interest was the spherical harmonic analyses of the data. The techniques discussed in this report were more thoroughly analyzed by Colombo (Sci. Rpt. No. 7, 1981). In this report the role of two-dimensional Fourier analysis in spherical harmonic analysis is discussed. These procedures were used to develop highly efficient computer programs to generate data on a grid from a given set of spherical harmonic coefficients, and to generate coefficients from a set of given data, either point or mean values. As an example, the computer time (on an Amdahl 470/V6, II) to generate a set of spherical harmonic expansion to degree 300 from 64800 $1^\circ \times 1^\circ$ mean values was 36 seconds.

This Colombo report was also important because it showed how the size of the mean blocks being used as data, aliases the coefficients being computed. This was crucial in identifying sampling error as well as data noise in estimating the accuracy of the computed quantities.

Analysis of Satellite-to-Satellite Tracking Data

The main concern in this area is the development of techniques for the processing of SST tracking data that might be expected from the GRAVSAT mission. Rapp and Hajela (Sci. Rpt. No. 3, 1979), first studied the accuracy to be expected for $1^\circ \times 1^\circ$ mean anomaly determination from a GRAVSAT type of mission. Rummel (Sci. Rpt. No. 6, 1980) postulated various data distributions and used least squares collocation to estimate the accuracies of various quantities of interest. Hajela (Sci. Rpt. No. 9, 1981) made the first attempt at a simulation study to examine the accuracy of anomaly recovery using collocation. In this study range-rate data was generated by Wong and Sjogren given a set of $1^\circ \times 1^\circ$ mean anomalies. Hajela's attempt at the recovery of the starting anomalies was moderately successful.

The fundamental problem in the above analyses was the limitation imposed by data density and the number of data points that could be used in a usual least squars collocation solution. Colombo (Sci. Rpt. No. 10, 1981) developed a collocation procedure to analyze the SST data to recover spherical harmonics. An actual simulation was run with a 6 month set of data points to determine the accuracy in which the harmonics could be determined. This procedure, expanded, perhaps, to consider orbit error, may be the way for an actual data analysis since the method can handle large data sets in a reasonable amount of time in an optimum way.

Another look at large dense data sets has been done by Rummel (1981). Although the method of Rummel was developed for the analysis of altimeter data, its applicability can be expanded to SST data.

Global Gravity Field Modelling

We continued to study ways in which the earth's gravity field could be determined and analyzed from existing data, Rapp (Sci. Rpt. No. 2, 1979) examined the problem of having a good anomaly degree variance model for covariance computations. New,one and two component models were developed using the results of a spherical harmonic expansion to degree 180 made in 1978.

Many combination solutions had been carried out using 5° mean anomalies. A study was made to see the effect of using 5° or 1°x 1° data in a combination solution. The results were described by Rapp (Sci. Rpt. No. 5, 1980), who showed that differences (between using 5° and 1° data) of 50% could occur at degree 36. Such differences were later verified in an analytical and numerical manner by Colombo (Sci. Rpt. No. 7, 1981).

In 1981 a substantial effort was made to develop a new spherical harmonic expansion of the earth's gravity field. This solution (Rapp, Sci. Rpt. No. 12, 1981) was carried out to degree 180 using Seasat altimeter data, new terrestrial 1°x 1° data, and a new a priori set of potential coefficients obtained from satellite analysis. The combination procedures used techniques and some programs developed by Colombo (Sci. Rpt. No. 7, 1981) earlier.

Although our analysis has been with spherical harmonics, there has been a concern on the evaluation of functions at the surface of the earth from such expansions. Jekeli (Sci. Rpt. No. 11, 1981) analyzed the downward continuation using some very high degree (up to degree 300) expansions. In doing this actual models of the earth's topography were used. The results obtained indicated corrections to the anomalies and undulations could reach 86 μgal and 410 μm. These values are considered negligable with respect to other error sources.

Another aspect of gravity field modelling is related to the computation of the gravity vector in space. Of special concern is the vector, near the surface of the earth, where the classical techniques are no longer valid. Katsambaios (Sci. Rpt. No. 8) studied this problem using topographic models and anomaly fields generated by point masses. He found that classical techniques could be seriously in error for points on the order of 1 to 10 km above the terrain. Katsambalos developed significantly improved techniques for this type of computation.

Vertical Datum Problem

Because of sea surface topography the mean ocean surface is not the geoid. Since height datums are based on mean sea level, such datums are not defined with respect to the same equipotential surface. The question then arises as to how one generates a unique vertical datum, or corrects existing vertical datums. Our first study was carried out by Colombo (Sci. Rpt. No. 4, 1980). In this report, Colombo showed how it would be possible to correct datums. The data needs were extensive, requiring precise (±10 cm) station coordinates. Accurate levelling between selected stations and a master station in a network, and geoid (spherical harmonic) and local (anomaly) gravity data. With some reasonable assumptions Colombo showed the correction of datums was a feasible procedure.

Some studies were attempted to determine the accuracy of which a vertical datum correction could be made with data available today. Unfortunately these studies were inconclusive because of the questions that exist on the accuracy and distribution of the needed data.

Rapp (1980) also discussed the concept of the vertical datum question. Here the incorporation of sea surface topography and satellite altimetry was discussed.

3. Personnel

The following Graduate Research Associates were employed under this promect: Chris Jekeli, Kostas Katsambalos, T. Saito. The following Post Doctoral Researchers were employed under this project: Oscar Colombo, D.P. Hajela, And Reiner Rummel. Pamela Pozderac and Susan Carroll provided secretarial support. Richard H. Rapp was the principal investigator and project supervisor.

4. The Scientific Reports Produced Under the Contract

Sci. Rpt. No.

1 Colombo, O., Optimal Estimation from Data Regularly Sampled on a Sphere with Applications in Geodesy, Dept. of Geodetic Science Report No. 291, AFGL-TR-79-0227, Sci. Rpt. No. 1, 29 pages, September 1979.

2 Rapp, R.H., Potential Coefficient and Anomaly Degree Variance Modelling Revisited, Dept. of Geodetic Science Report No. 295, AFGL-TR-79--245, Sci. Rpt. No. 2, 18 pages, September 1979.

3 Rapp, R.H., and D.P. Hajela, Accuracy Estimates of $1^\circ \times 1^\circ$ Mean Anomaly Determinations from a High-Low SST Mission, Dept. of Geodetic Science Report No. 295, AFGL-TR-79-0269, Sci. Rpt. No. 3, 12 pages, September, 1979.

4 Colombo, O., A World Vertical Network, Dept. of Geodetic Science Report No. 296, AFGL-TR-79-C-0027, Sci. Rpt. No. 4, 63 pages, February 1980.

5 Rapp, R.H., Comparison of Potential Coefficient Determinations with 5° and 1° Anomalies, Dept. of Geodetic Science Report No. 300, AFGL-80-0160, Sci. Rpt. No. 5, 11 pages, April, 1980.

6 Rummel, R., Geoid Heights, Geoid Height Differences, and Mean Gravity Anomalies from "Low-Low" Satellite-To-Satellite Tracking--An Error Analyses, Dept. of Geodetic Science Report No. 306, AFGL-TR-80-0294, Sci. Rpt. No. 6, 44 pages, June 1980.

7 Colombo, O., Numerical Methods for Harmonic Analysis on the Sphere, Dept. of Geodetic Science Report No. 310, AFGL-TR-80-0038, Sci. Rpt. No. 7, 140 pages, March 1981.

8 Katsambalos, K., Simulation Studies on the Computation of the Gravity Vector in Space from Surface Data Considering the Topography of the Earth, Dept. of Geodetic Science Report No. 314, AFGL-TR-81-0187, Sci. Rpt. No. 8, 136 pages, June 1981.

9 Hajela, D.P., A Simulation Study To Test the Prediction of $1^\circ \times 1^\circ$ Mean Gravity Anomalies Using Least Squares Collocation from the Gravsat Mission, Dept. of Geodetic Science Report No. 316, AFGL-TR-81-0302, Sci. Rpt. No. 9, 52 pages, September, 1981.

10 Colombo, O., Global Geopotential Modelling From Satellite-to-Satellite Tracking, Dept. of Geodetic Science Report No. 317, AFGL-TR-81-0319, Sci. Rpt. No. 10, 137 pages, October 1981.

11 Jekeli, C., The Downward Continuation to the Earth's Surface of Truncated Spherical and Ellipsoidal Harmonic Series of the Gravity and Height Anomalies, Dept. of Geodetic Science Report No. 323, AFGL-TR-81-0361, Sci. Rpt. No. 11, 145 pages, Dec. 1981.

12 Rapp, R.H., The Earth's Gravity Field to Degree and Order 180 Using Seasat Altimeter Data, Terrestrial Gravity Data, and Other Data, Dept. of Geodetic Science Report No. 322, AFGL-TR-82-0019, Sci. Rpt. No. 12, 52 pages, December 1981.

5. Other Papers and Presentations

Colombo, O., A World Vertical Network, presented at the American Geophysical Union meeting, Washington, D.C., May, 1979.

Colombo, O., Algorithms for Spherical Harmonic Analyses, presented at the American Geophysical Union meeting, San Francisco, December 1979.

Colombo, O., Transoceanic vertical datum connections, in proceedings, Second Int. Symp. on Problems Related to the Redefinition of North American Vertical Geodetic Networks, Ottawa, 1980.

Rapp, R.H., Precise definition of the geoid and its realization for vertical datum applications, in proceedings, Second Int. Symp. on Problems Related to the Redefinition of North American Vertical Geodetic Networks, Ottawa, 1980, The Canadian Institute of Surveying, Box 5378, Station F, Ottawa, Canada K2C351

Rapp, R.H. Should 5° Mean Anomalies be Used in Combination Solutions for the Earth's Gravity Field, presented at the American Geophysical Union meeting, Toronto, Canada, May 1980.

Rummel, R., Error Analyses of Low-Low Satellite-to-Satellite Tracking, paper presented at the symposium, "Geodesy and Physics of the Earth", Karl-Marx-Stadt, East Germany, May, 1980.

Rummel, R., Gravity Parameter Estimation from Large and Densely Spaced Homogeneous Data Sets, presented at the 8th Hotine Symposium on Mathematical Geodesy, Como, Italy, Sept. 1981.

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